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Effects of Motion on Skill Acquisition in Future Simulators

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14. ABSTRACT *(Maximum 200 words)*:

In order to develop recommendations for the use of motion in ground vehicle simulators, a thorough literature review was conducted. Literature on motion cueing theories as well as basic and applied research in the use of motion in simulation was examined. A particular focus was paid to research on the effects of motion cueing on transfer of training from both ground vehicle and aircraft simulators. From the information gathered in the literature reviews on motion cueing, recommendations for the use of motion in ground vehicle training simulation were developed. In addition to motion cueing factors, theories and applied research on motion sickness were also investigated. As motion sickness holds the potential to significantly affect performance both in a simulator and in an actual ground vehicle, it was considered important to develop recommendations for the use of simulator motion to mitigate these effects. Guidelines were developed from the information gathered in this review for the use of simulator motion in training to diminish the effects of motion sickness.

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EFFECTS OF MOTION ON SKILL ACQUISITION IN FUTURE SIMULATORS

EXECUTIVE SUMMARY

Research Requirement:

One of the major high-cost decisions in the procurement of simulators for vehicle training is whether the simulator should have a motion component. Adding motion to simulators is costly and complex. Because of the cost, motion is only justified if it improves Soldier's performance on the real vehicle. However, there are questions concerning whether motion in simulation transfers to performance in the real-world vehicle. There is a general belief in the training community that the more realistic the simulation, the better training the Soldier receives, however, research has not supported this belief.

Additionally, the issue of simulator motion is not a yes-or-no question. Motion in simulators may improve training for certain tasks and under certain conditions, but not others. This adds to the complexity of the decision of whether vehicle simulators require motion.

To help with this decision, those involved in the acquisition of ground vehicle simulators need guidelines concerning what situations require motion for simulator training. Such guidelines must be based on relevant human performance research. Therefore, the Training and Doctrine Command (TRADOC) Program Integration Office (TPIO) Virtual, who provides overall system management for current and future simulators, asked the U.S. Army Research Institute for the Behavioral and Social Sciences to sponsor research to develop such guidelines.

Procedure:

In order to develop recommendations for the use of motion in Future Forces ground vehicle simulators, a thorough literature review was conducted across several lines of research. First, a review of the literature on motion cueing theories as well as basic research on motion cueing was examined. This was done to establish a theoretical and human-performance framework with which to examine the applied work in simulator training. Next, was a review of the research in the use of motion cueing in applied simulator training. A particular focus was paid to research on the transfer of training from simulators. Two general areas of applied simulation research were investigated, these were ground vehicle and aircraft simulation. Unfortunately, few studies on motion cueing and transfer of training in ground vehicle simulation were found. This led to the use of aircraft simulation research as the main source of data to guide in the development of motion recommendations.

In addition to motion cueing factors, theories and applied research on motion sickness were also investigated. As motion sickness holds the potential to significantly affect performance both in a simulator and in an actual ground vehicle, it was considered important to develop recommendations for the use of simulator motion to mitigate these effects. The research

in this area was used to develop guidelines for the use of simulator motion in training to diminish the effects of motion sickness.

Findings:

From the information gathered in the literature reviews on both motion cueing and motion sickness, two sets of motion recommendations were developed. First, a task taxonomy was used to define the task characteristics that would determine where motion was necessary in simulator training. Tasks that were determined to be skill-based behaviors according to Rasmussen's Skill, Rule, Knowledge (SRK) taxonomy were deemed to be ones where simulator training would be of particular benefit. Within the skill-based tasks, a division between tracking and disturbance management was determined to drive the decision of whether motion was needed. Specifically, the training of disturbance management tasks, such as dealing with rough terrain is specifically enhanced by the addition of vestibular motion cues. Therefore, it is recommended that for training basic tracking vehicle control skills, motion is not needed. For training more advanced disturbance control skills, motion would be of benefit.

For motion sickness, it was determined that training involving exposure to motion could be used to effectively bring about adaptation to the motion environment and thereby reduce symptoms. This adaptation should occur in a motion environment very similar to the real-life motion that is expected in order to maximize transfer. In addition, adaptation does tend to degrade over time, however, refresher training can be used periodically for maintenance.

Therefore, motion-based simulators are recommended for training when individuals must continue to perform skill-based tasks (those involving smooth, automated, sensory-motor performance such as driving, gunnery, or operating controls) while the ground vehicle negotiates rough terrain. The characteristics of the motion, e.g. axes and magnitude, should approximate that which the vehicle occupants undergo while traveling over rough terrain. In this case a motion-based simulator is important for several reasons. First, it should allow individuals to develop strategies for disturbance management, that is, to continue task performance while experiencing the extreme irregular motion caused by the vehicle traversing rough terrain. Second, it may help individuals who are prone to motion sickness adapt to the motion and therefore experience fewer or less severe symptoms.

Conversely, in situations where individuals are not required to perform tasks while negotiating rough terrain (e.g. vehicles that do not travel off-road or when tasks are only performed when the vehicle is stopped), and/or motion sickness does not detract from task performance, motion is not recommended.

Utilization and Dissemination of Findings:

This report provides guidelines, based on human performance research, that can help those who design and acquire future ground vehicle simulators decide for what tasks and under what conditions motion-based simulators will improve Soldier performance in real vehicles, and

also for what tasks and under what conditions motion is not required. These guidelines ensure future ground vehicle simulators can be procured in a cost-effective manner and still deliver appropriate, effective training.

EFFECTS OF MOTION ON SKILL ACQUISITION IN FUTURE SIMULATORS

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Introduction

Simulator realism or, as it is usually referred to, simulator fidelity comes at a price, the more realistic a simulator needs to be, the more expensive it will be to build and maintain. Because of reductions in the cost of computer technology, this is less true today than it was a decade ago, but there is still some truth to the notion, particularly when it comes to aspects of realism that are hardware, not software dependent. An excellent example of this is adding simulator motion cueing, something that, most definitely, can not be done in software.

Does a simulator need motion to provide adequate fidelity for training military tasks? As always when it comes to questions about what is needed in a training environment to provide an effective medium, the answer to this question often depends greatly on the nature of the task. This is a fundamental factor that can drive simulator fidelity needs and is at the heart of the "is motion really needed?" question.

Simulator Motion Requirements – A Question That Has Been Investigated in a Different Domain

The issue of "is motion needed?" is, in fact, an old question to the aviation simulation community. From the mid-1970s, this issue was addressed significantly by the military and commercial aviation communities. The issues that drove the research were essentially the same as those faced today: a) the aviation community was relying increasingly on simulation as the medium for training, b) motion systems were expensive, so c) when and why was motion needed?

At the end of this period of research, a model of aviation simulator fidelity requirements emerged that is largely followed today. Essentially, most training up to the later stages of simulator training is performed without motion-based simulators. However, the later stages of training and when simulators are used for testing and licensing (e.g., Federal Aviation Administration [FAA] qualification tests), motion-based simulators are used. What drove the need for motion was, however, not a strong base of research supporting the superior training effectiveness or first trial skill transfer of motion-based simulators but, rather, pilot acceptance. This was, in the end, the deciding factor.

It is also worth noting that the aviation training metaphor is different in one fundamental way from Future Force training issues, the ratio of flight training vs. simulator costs in aviation is considerably higher than the ratio of field training vs. simulator costs in the Army. In the end, the relatively high cost of flying compared to the cost of aviation simulators, with or without motion, made the decision relatively easy, whatever would get the aviation community to use the simulators, including motion platforms, was worth it.

Army Future Force Training – A Different Set of Questions?

Can we extrapolate the findings with respect to the value of motion from the aviation research community to Future Force training system design? The aviation research community focused on the issue of motion from the perspective of, "is it a key cue to the human in defining his required attention management and control inputs?" The issue of motion cueing will once again become important in the training of operators of Future Forces ground vehicles. One question we must ask is "what are the similarities between these aviation tasks and ones performed by the Soldiers operating ground vehicles?" In addition, "to what degree can the knowledge gained from aviation research on motion cueing in a simulation training environment

be applied to the development of recommendations for the use of motion in ground vehicle simulation training?"

Additional lines of research that were performed by the aviation simulation community were the causes of and potential mitigation strategies for motion sickness. It is well documented that motion sickness is a potentially enormous problem on the Future Force battlefield (e.g., Burcham, 2002). Many, if not most, people are prone to motion sickness when they are operating computer terminals in a moving enclosed space, as will be the case in many Future Force vehicles. Overcoming motion sickness is a central issue that must be addressed for some of the Future Combat Systems (FCS) concepts to be fully realized. Furthermore, there is evidence (Cowings & Toscano, 2000) that motion sickness can be overcome through training, and there are centuries of experience at sea that tell us that sea sickness can be overcome. A controlled simulation environment offers great promise in averting the battlefield crisis induced by motion sick command and controllers.

Literature Review

Motion Cueing

For a long time, it has been conventional wisdom that when using a simulator as a training device, the more realistic the simulation, the more beneficial it will be in aiding skill acquisition (Ornstein, Nichols, & Flexman, 1954; Osgood, 1949). However, with respect to motion cueing in simulators, this view has not been well substantiated in the transfer of training literature (Burki-Cohen, Soja, & Longridge, 1998; Go, Burki-Cohen, & Soja, 2000; Go, Burki-Cohen, Chung, Schroeder, Saillant, Jacobs, & Longridge, 2003; Gray & Fuller, 1977; Koonce, 1974; Martin & Waag, 1978a, 1978b; Pohlmann & Reed, 1978; Waag, 1981). In recent years newer and more refined theories on the role of motion cueing in skill acquisition with aircraft and vehicle simulators have been put forward (Advani & Hosman, 2001; Hosman & Stassen, 1999; Hosman, Advani, & Haeck, 2002). These authors have drawn some meaningful distinctions on the relative contributions of visual and vestibular motion cues in a training environment. Out of this has come the notion that simulator motion is not always necessary for the acquisition of skill. Instead of the "more realistic the better" position, now there is the thought that motion may be necessary to train some types of tasks but may not be required for others. The determination of what tasks will require simulator motion depends upon two main characteristics of the task. First the task should be categorized as a skill-based behavior according to Rasmussen's (1983) Skill, Rule, Knowledge (SRK) taxonomy. Second, there is a distinction made between tracking and disturbance management tasks with the latter being the one requiring vestibular motion cueing.

In order to see how these distinctions apply to driving tasks, as well as to the design and implementation of simulator motion for training, there are several concepts that need to be examined. First an explanation of the importance of the SRK taxonomy to training will be outlined. Second the distinction of tracking versus disturbance management will be defined. Lastly, there will be a review of the literature on the transfer of training with simulator motion.

Skill, Rule, Knowledge Taxonomy. Rasmussen's (1983) SRK taxonomy is a structure used to describe different categories of human performance. This taxonomy was developed in

order to help organize knowledge of human performance and behavior into a form that would be beneficial in system analysis and design. While the SRK taxonomy is not intended to be a comprehensive model of human cognition, it does draw some meaningful distinctions between different types of behaviors. Moreover, these distinctions can help guide a designer's thinking about how an operator would interact with a system.

The SRK taxonomy divides human performance into three discrete levels or categories. These categories are skill-based (SBB), rule-based (RBB), and knowledge-based behaviors (KBB). Each of these represents a distinct level of cognitive control or interaction with the environment. The distinguishing characteristic that creates the division between these levels of cognitive control in the SRK taxonomy is the type of internal mental representation that is used to guide behaviors at that level. These are mental representations of the constraints or invariants in the environment that can be perceived and that will have an effect on action (Rasmussen, 1983).

The lowest level of cognitive control within this taxonomy, SBB is characterized by smooth, automated, sensory-motor performance (Rasmussen, 1983). These are specialized and highly integrated patterns of continuous behaviors that take place without conscious control through a direct coupling between the individual and the environment. At this level, information from the environment is perceived as continuous signals that guide action in real time. An example of SBB would be a tracking task where physical control inputs are directly coupled to the state of the environment through these signals. Another example of SBB would be walking, where the physical movements are elicited by information from the environment in real time in a smooth, dynamic fashion with little or no cognitive intervention.

SBB is made possible by what Rasmussen (1983) calls a *dynamic world model.* This is an implicit mental representation of the goal relevant constraints in the environment. It functions something like a schema for complex movements with respect to those constraints. This dynamic world model is built up over time as an individual acquires experience in interacting with a system or environment under similar conditions. For example, experience allows us to steer a car while on the highway, or climb a flight of stairs without having to exert cognitive control over the fine motor movements of the behavior. Therefore, experience with actions allows us to develop these implicit representations of how perceived constraints and actions interact. This dynamic world model then supports SBB by allowing a direct coupling between the individual and the environment. This coupling results in the continuous, real-time, interactions between the individual and his or her environment that typify SBB.

The next level of cognitive control described by Rasmussen (1983) is RBB. Within this level of cognitive control, the constraints in the environment that affect behavior are represented as stored rules. These rules are used in a similar fashion to *if-then* statements where actions are triggered directly by familiar perceptual cues, or invariants in the environment. These rules are created in several ways. They can be the result of previous experience with similar situations. They can be created through instructions communicated by others either verbally or in written form, such as pre-prescribed procedures. Also, they can be created "on the fly" through problem solving or planning in anticipation of certain circumstances or cues that would trigger a behavior.

With SBB, the information from the environment is perceived as continuous signals, whereas the information that triggers RBB is perceived as *signs*. These signs are the familiar environmental cues or invariants that directly elicit behaviors. Because both consist of automated types of behaviors directly elicited from environmental cues, the distinctions between SBB and RBB can become somewhat fuzzy. The main differences between them primarily lie in the level of cognitive attention and how the environmental constraints are perceived and used. During SBB, behavior continues without cognitive control in a smooth automated fashion. Individuals engaging in SBB are unable to describe how and why they are performing a task. This is unlike RBB, where the cues and resulting behaviors can be described by the individual.

SBB can be thought of as being a continuous flow of action as a result of the direct coupling between the individual and environment, whereas RBB are more discrete behaviors or sequences of behaviors that are triggered by specific environmental signs. Using a driving example, the act of tracking within a lane on the highway could be done at the level of SBB where the position of the car in the lane and with respect to other cars over time are perceived as time-space signals that drive the smooth behaviors in controlling the steering wheel, accelerator and brake pedal. If one sees a stop sign ahead, this might trigger a rule to slow down thus start downshifting and pressing the brake pedal. While performing these behaviors, the operator would be unable to detail specifically what is driving the behaviors of tracking at the SBB level, only some idea of the basic goal. But, the rule that is triggered by the perception of a stop sign could be verbalized in a fashion such as "I saw the stop sign, so I knew I needed to stop." This "sign" triggered the actions required to stop the car at the appropriate place.

The highest level of cognitive control in the SRK taxonomy is KBB (Rasmussen, 1983). During unfamiliar situations, when no skills or rules are available for immediate use, this type of behavior is triggered. Typically, this level of cognitive control consists of serial, effortful, and deliberate cognitive activities. These cognitive activities are performed utilizing a mental model of the work domain. This mental model constitutes the way in which the goal-relevant constraints in the environment are represented at this level of cognitive control within the SRK taxonomy. KBB usually consists of analytical reasoning, thought experiments and planning activities, where the goal is explicitly formulated by the individual and is used to compare possible alternatives when trying to select appropriate actions. During KBB, the constraints in the environment are perceived as symbols, as opposed to signs or signals. These symbols are used in reference to the symbolic representation of the work domain at this level of cognitive control that is the mental model that guides KBB.

As stated previously, there is often a strong interaction between the three levels of cognitive control during the performance of any task. It is not the case that any of these levels of cognitive control are used to the exclusion of the others at any one time. While performing any task, it is often the case that one is performing at two or all three levels simultaneously. For instance, returning to the driving task, one may be using skill-based interactions in the physical tracking of the car within the lane on the highway while simultaneously, using rule-based interactions brought about by road signs or brake lights of cars ahead. While this is going on, (KBB) are occurring as the driver is using information gathered from the exit sign just ahead to reason whether this is the correct exit or not based on their mental model of the local area's road

system. This example illustrates the dynamic nature of the different levels of cognitive control as described by the SRK taxonomy.

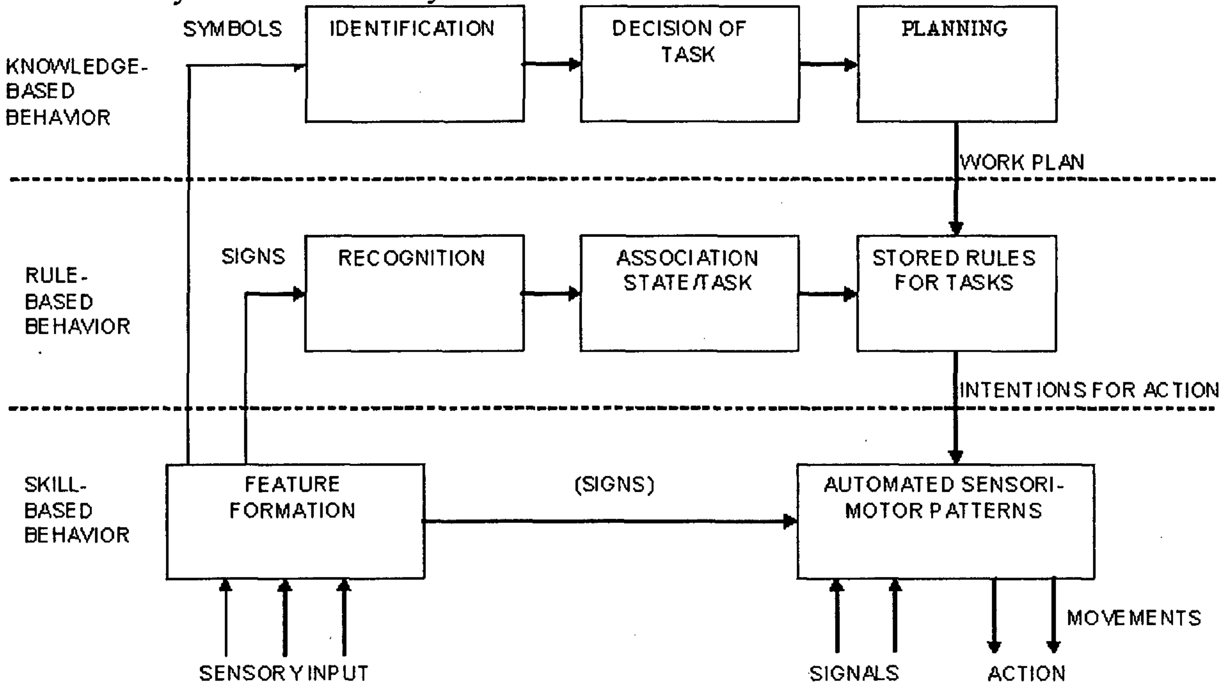

Figure 1. Skill, rule, knowledge taxonomy (after Rasmussen, 1983).

Another way that interaction occurs between levels of cognitive control is in the nesting of the "output" side of the SRK taxonomy (see Figure 1). Here, essentially all roads to behavior lead through lower levels of cognitive control, or in other words, the outputs of any level need to pass through the levels below it on the way to physical motor movements. So, KBB will create a plan for work or actions, which feed into RBB in which this plan is used to set up rules that create intensions for action. These rules are fired by the perception of the signs dictated by the previous KBB planning activities. These RBBs are then fed into SBBs where these intensions are rules that update or select the dynamic world model which then guides the ultimate motor actions themselves as SBB (Rasmussen, 1983). Figure 1 shows a graphical representation of the three levels of cognitive interaction described by the SRK taxonomy along with their hierarchical arrangement.

SRK and training considerations. Advani and Hosman (2001) argue that the level of behavior within the SRK taxonomy that a task falls into is an important consideration in the development of training strategies for that task. KBB rely on an accurate mental model for performance. The information that is used to build this mental model can be learned largely through training in a classroom. RBB are effectively procedural and tied to recognition of cues. Therefore, these types of behaviors can effectively be trained through the use of part-task devices such as procedural trainers (Advani & Hosman, 2001; Hosman, 1999). SBB are based on a dynamic world model where the control characteristics of the system and how that system (in this case a ground vehicle) interacts with its environment are of critical importance. Therefore, SBB and the integration with the other levels of behavior should be trained with correct vehicle characteristics. This can be accomplished either in the actual vehicle or in a simulator.

For a vehicle driver, the types of tasks that are categorized as SBB are generally manual control tasks such as maneuvering a vehicle through terrain or even just driving on a straight road. In a simulator, motion cues are critical for the performance of skill-based, manual control behaviors because these cues form the basis of the time-space signals that drive SBB. These motion cues can be perceived in two ways, visual and vestibular. Perception of motion through the visual system comes from the simulator's display of the visual scene in motion corresponding to the vehicle's movement through the environment. Motion can also be perceived by stimulation of the vestibular system from a mechanical motion base. These two types of motion cues need to give an accurate perception of the motion of a vehicle through an environment if manual control skills are to be learned effectively. Since motion bases are relatively expensive and often take up a considerable amount of space, the importance of vestibular motion cues in manual control skill acquisition becomes a significant question.

Tracking versus disturbance management. The relative impact of visual and vestibular motion cues in facilitating SBB has been addressed in the recent literature for both aircraft (Hosman & Stassen, 1999; Hosman et al., 2002; Hosman & van der Vaart, 1981; 1990) and ground vehicles (Advani & Hosman, 2001). These authors have found that manual control tasks in both driving and flying can be broken down into two general types: tracking and disturbance management. Tracking tasks involve following a prescribed trajectory such as staying within a lane on a road or exiting on an off-ramp while correcting for control errors. Visual perception is the primary source of information with tracking tasks. Relative position of the vehicle with respect to the intended trajectory as well as any control errors are perceived visually and this information guides the tracking behaviors (Advani & Hosman, 2001; Hosman, 1999; Hosman & van der Vaart, 1990). Therefore, with tracking tasks, it is visual rather than vestibular motion cueing that is primarily needed for performance.

Disturbance management tasks involve control corrections of the vehicle due to perturbations (Advani & Hosman, 2001). These disturbances can come from outside sources such as a gust of wind or uneven terrain as well as from internal sources such as a mechanical malfunction (tire blow out, etc.). Motion cueing is important for performance during disturbance management tasks. Hosman & van der Vaart (1981, 1990) performed a series of experiments to assess the relative impact of visual and vestibular motion cues on pilot's tracking and disturbance management performance. They found that for disturbance management tasks, vestibular motion cues played a much greater role in performance than they did for tracking tasks. Therefore, the relative importance of visual and vestibular motion cues is very different with disturbance management. Vestibular motion cues become much more central in the effective control of a vehicle when dealing with a disturbance. In addition, Advani & Hosman (2001) used a human perception model (Bussolari, Young & Lee, 1989; Hosman & Stassen, 1999), within a ground vehicle control simulation to assess the impact of visual and vestibular motion cues in controlling a vehicle during tracking and disturbance management tasks. The results of this research indicated that for tracking tasks, visual motion cueing was sufficient, however, for disturbance management tasks, the addition of vestibular motion cueing greatly increased performance. A similar experiment was performed by Hosman et al. (2002) in which they used an aircraft control simulation and obtained similar results. Therefore, the distinction between tracking and disturbance management with respect to the relative importance of visual and vestibular motion cues holds for both aircraft and ground vehicles.

When applied to requirements for motion in ground vehicle simulations, these findings suggest several things. First, for training general driving tasks, which involve almost entirely tracking behaviors, simulator motion in most cases would not be necessary for skill acquisition. Second, when training more advanced driving techniques such as rough terrain negotiation, disturbance management tasks are more prevalent. For training these types of skills, simulator motion will be required in order to provide the vestibular motion cueing necessary for skill acquisition and performance.

Transfer of Training

A great deal of research has been conducted on the training benefits of simulators. Much of the research available, however, does not look at how the trained skills in the simulator transfer to the real world. Many people mistakenly equate performance observed in a simulator with transfer of these skills to the actual system. This may seem like a reasonable assumption; however, research has shown that the transfer of performance in a simulator to the real world is more complex. Koonce (1974) showed that observed performance differences in aviation simulators with varying amounts of vestibular motion cues did not transfer directly to a real aircraft. The results showed that although the observed performance in a motion-based simulator was superior to a fixed-base simulator, when transitioning to the real aircraft, performance results were reversed. As a result of these differences it is important to make a distinction between two general types of simulator training research. One type deals primarily with performance differences in the simulator while the second type focuses on the transfer of performance from the simulator to the real world. Since the primary concern is the development of recommendations for simulator motion to support effective training and transfer of this training into the actual vehicle, it is this second type of research, transfer of training, which is the focus of this effort.

Transfer of training is "the degree to which trainees effectively apply the knowledge, skills, and attitudes gained in a training context to the job" (Baldwin & Ford, 1988, page 63). Within the context of training manual vehicle control skills in a simulator, transfer of training would be the degree to which the skills learned in the simulator are demonstrated in controlling the real vehicle. The assessment of motion cues' impact on transfer of training is typically evaluated by measuring post-training performance differences in participants receiving different types and/or levels of motion cues. The conditions under which post-training performance is measured creates a division between two general types of transfer of training studies. The first type of transfer of training research measures post training performance in the actual system that the simulator is based on, for instance, a real aircraft or ground vehicle. This type constitutes the traditional transfer of training research. Often, it is not feasible, either due to safety or monetary reasons to measure post-training performance in the actual vehicle or aircraft. As a result, either an alternate simulator or a reconfiguration of the training simulator is used to measure post-training performance. This type of methodology is referred to as quasi-transfer of training.

The majority of research examining transfer of training comes from the aviation field. A thorough examination of the use of ground vehicle simulators while presenting some interesting findings contains very little in the area of transfer of training. A thorough review of the literature written on the effects of ground vehicle simulators with or without the use of motion platforms

have in general yielded useful findings on driving performance within the simulator. In general, this research has demonstrated more realistic driving performance in a simulator that has a motion platform (Blana & Golias, 1999; Boer, Yamamura, & Kuge, 2001; Boer, Yamamura, Kuge, & Girshick, 2000; Frank, Casali, & Wierwille, 1988; Reymond, Kemeny, Droulez, & Berthoz, 1999; Reymond, Kemeny, Droulez, & Berthoz, 2001). Even though motion bases in driving simulators were shown to improve performance within the simulator there were no experiments that evaluated whether these performance differences transferred to an actual vehicle. Based on research that will be discussed using aircraft simulators it is reasonable to assume that transfer of these performance differences may not occur.

With virtually all research on driving simulators focusing on simulator performance rather then transfer of training, research in the aviation field was used as the primary source of information. Through an analysis of the aviation simulator transfer of training research conducted over the past 35 years, certain patterns have appeared. Through these emerging patterns, principles on how and why to use motion in training simulations become more apparent. With Advani & Hosman (2001) and Hosman et al. (2002) demonstrating that the effects of visual and vestibular motion cues are comparable between aircraft and ground vehicles, the use of aircraft simulator research should provide us with information useful in developing motion guidelines for ground vehicle simulators.

Pre-1990 research. An early analysis of the effectiveness of using vestibular motion cues within aviation training simulators performed by Jacobs (1976) concentrated on transfer of training under different motion conditions. Researchers used participants with no prior flying knowledge assigned to one of three training groups. One group received training in a simulator with the motion base deactivated, therefore receiving no vestibular motion cues. A second group was trained in the simulator with the motion base providing roll and pitch motion only. The final group received training with the simulator providing motion which was randomized in such a way that it provided alerting cues that were not reliable direction cues. The aircraft training for all groups consisted of basic beginning flight maneuvers which are essential components of more advanced maneuvers. Pilot performance during simulator training was measured by mean time to criterion, mean trials to criterion, and the number of errors, where errors are defined as violations of FAA private-pilot flight check standards. After completing the entire training curriculum in the simulator, participants were placed in a real aircraft where their performance was measured. These performance ratings were used as the basis to assess the transfer of flight skills to the real aircraft.

The results of this research found that while in this simulator, the performance of the standard motion group was superior to that of both the non-motion and random motion groups. However, when transitioned into the real aircraft all performance differences between the groups disappeared. Therefore, while motion seems to have produced better performance in the simulator this performance advantage did not transfer to the actual aircraft. From the results of this research, Jacobs did not find reason for the necessity of motion in aircraft simulator training. It should be noted that only tracking control behaviors were used in this research and so this tends to agree with Hosman and Stassen's (1999) assertion that vestibular motion cues are not specifically necessary for acquisition of tracking control skills.

In addition to looking at performance differences, Jacobs (1976) also investigated the participants' perceptions of the motion cues used in the experiment. After completion of the simulation training session participants were asked about their views on the implementation of motion. The participants usually either did not notice the presence of or miss the absence of motion cues, depending upon their assigned training group. Interestingly the experimental group assigned to the random motion group did not even notice that the motion cues were incorrect.

The inclusion of a motion platform for aviation training has mostly been concerned with performing aerial maneuvers. However, researchers have also explored its use in air-to-surface weapons delivery training. Gray and Fuller (1977) trained recent United States Air Force undergraduate pilot training graduates on an air-to-surface weapons delivery curriculum. The participants were assigned to one of three groups, two of which received training in a flight simulator, the third receiving traditional classroom training. Of the two simulator training groups, one received 6 degree of freedom platform motion while the other group received no motion. After completion of training, participants transitioned into real aircraft where they were required to drop munitions on a bombing range. Performance was defined as the distance the bombs impacted from specified targets on the range.

The results of this research showed that both simulator groups' performance was significantly better then the control group that only received classroom training. With respect to the two simulator training groups, no significant performance difference was found. Gray and Fuller (1977) concluded that simulator training did transfer to the actual aircraft however the inclusion of platform motion did not increase the level of transfer. The assertion made by Advani and Hosman (2001) and Hosman (1999) that the effective acquisition of skill-based manual control behaviors require accurate system characteristics, as would be found in a simulator, was supported by the superiority of the simulator training groups over the classroom training group. In addition, this research also agrees with Hosman and Stassen's (1999) statement that vestibular motion cues are not specifically necessary for acquisition of tracking control skills.

Martin and Waag (1978a, 1978b) studied transfer of aviation maneuvering skills in a pair of experiments. The primary difference between these two experiments was the type of maneuvers being assessed, which were basic control and aerobatic maneuvers. In both of these experiments the researchers assigned participants, comprised of U.S. Air Force novice pilots, into one of three groups: simulator training with motion (6 degree of freedom), simulator training with no motion, and a control group that received traditional classroom training. The participants' performance, both within the simulator and in the real aircraft, was assessed by flight instructors scoring each maneuver performed on a twelve point rating scale.

The major findings of both experiments showed that performance within the simulator was not significantly different between the two simulator groups. The two simulator groups were also not significantly different in the performance of the skills transferred from the simulator to the actual aircraft. Participants trained on the simulator also showed significantly better performance in the actual aircraft over participants that only received traditional classroom training. The simulator was shown to be beneficial in skill acquisition; however the inclusion of vestibular motion cues did not significantly affect the training of tracking skills.

Following up on Martin and Waag's (1978a, 1978b) research efforts further experimentation was conducted by Nataupsky, Waag, Weyer, McFadden, and McDowell (1979) examining if an interaction between implementation of a motion platform and size of the visual FOV benefited skill acquisition. The experimenters recruited U.S. Air Force cadets with very little flight experience and trained them on a curriculum focused on conducting sorties. The participants were placed in one of four simulator groups, two of these groups used the training simulator with a full 6 degree of freedom motion platform activated, while the other two had the motion base turned off. The two pairs of groups were further divided by the degree of field of view, limited and full. The participants were evaluated on their performance after each of four consecutive training sessions in the simulator and post-training while performing sorties in a T-37 aircraft. Performance was assessed using the same twelve point rating scale employed in Martin and Waag (1978a, 1978b).

The results of this research found that for all groups, performance increased with successive training sessions. When examining ratings of performance in the simulator it was shown that regardless of FOV size, the groups with the motion base activated had significantly better performance than the groups with no motion. These performance differences during training disappeared once the participants were assessed in the real aircraft. Specifically, participants that received motion during training did not have significantly different performance than the no motion participants. These results suggested that there was no appreciable difference in the level of transfer of training between the groups. The authors concluded that no practical or substantial differences in transfer of training to real aircraft occurred as a result of the inclusion of motion.

1990 to present research. Based upon a lack of published research during the eighties and nineties, research examining the necessity of motion in training simulators appears not to have been actively studied during this time. Around 2000 it once again became a topic of interest for many researchers. The first new investigation of this decade (Go et al., 2000) examined the benefits of motion cues in training simulators. For participants, these researchers used regional airline pilots undergoing recurrent training and evaluation. This research focused on the effects of vestibular motion cues on pilot evaluation, training progress, and transfer of training. This discussion will focus primarily on the transfer of training portion of this research.

All of the participants received the same training curriculum in an FAA qualified level C flight simulator, capable of 6 degree of freedom motion. The participants were assigned to one of two groups, one in which the motion was activated, the other group received no vestibular motion cues. Post-training performance was evaluated for both groups using the same flight simulator with motion turned on, making this a quasi-transfer design. The researchers based the performance evaluation on two flight maneuvers, first an engine failure causing a rejected take-off (RTO) and second an engine failure where take-off could still continue (V1 cut). These tasks were chosen in accordance with an FAA approved training program. In order to meet FAA criteria, certain task characteristics must be present: (a) motion should be part of the control feedback loop to the pilot, (b) unpredictable and asymmetric motion disturbances that may bring to light possible alerting mechanisms, (c) high gain and thrust should be present to magnify motion effects, (d) high workload conditions such as crosswinds and low visibility that should provide an environment in which more sensory cues may be used by the pilot to increase

performance, and (e) short duration to prevent pilots from adjusting to a lack of cues. Pilot performance during training and post-training evaluation was based upon measurements of deviation from flight paths, reaction times to critical events during the tasks, and grades provided by flight instructors.

The data from this research paints much the same picture as other projects preceding it. When examining transfer of training for the RTO task, the groups did not perform significantly different depending upon their training group. The V1 cut task yielded similar findings. In general, there were no significant differences between the two groups. The authors arrived at a similar conclusion to others before them in that the results of this research do not show any inherent benefits in adding motion cues to training simulators when examining transfer of training or progress of training. This research has also been discussed in Burki-Cohen, Go, and Longridge (2001), Chung, Burki-Cohen, and Go (2004), Longridge, Burki-Cohen, Go, and Kendra (2001).

Go et al. (2003) examined the effects of motion cues on training and quasi-transfer. Current Boeing 747-400 pilots were assigned to one of two training groups, motion and no motion. The participants were trained on four separate maneuvers, two consisting of an engine failure during take-off, and two landing maneuvers with an engine out. This experiment used a National Aeronautics and Space Administration (NASA)-FAA B747-400 simulator providing state of the art visual and sound cues as well as a six degree of freedom hexapod motion platform.

Post-training performance differences were found in both landing maneuvers as well as during one of the take-off engine failures. The no-motion group performed the landing maneuvers with significantly more precision and less effort than their motion counterparts and also reacted more quickly during the engine failure. The authors felt that training the landing maneuvers without motion may lower the control activity and improve the performance of the pilot when transferred to a simulator with motion. They also stated that training pilots with motion cues may actually promote overcorrection during the tasks in this research, while training with no motion may allow for a pilot to develop a more stable control strategy. In conclusion no benefit was found for using motion in recurrent training. This research was also presented by Burki-Cohen, Go, Chung, Schroeder, Jacobs, and Longridge (2003).

Transfer of training summary. One of the first sets of findings that are important to note was the demonstration of the superiority of simulators over classroom instruction in the acquisition of manual control skills (Gray & Fuller, 1977; Martin & Waag, 1978a, 1978b). These studies provided evidence supporting the need for accurate systems dynamics in training skill based behaviors as claimed by Advani and Hosman (2001) and Hosman (1999). In addition, with regard to the importance of vestibular motion cues in the acquisition of tracking task skills, several studies demonstrated that vestibular cues did not increase the level of transfer (Jacobs, 1976; Martin & Waag, 1978a, 1978b). These findings also support the assertions of Advani and Hosman (2001) and Hosman and Stassen (1999) that visual rather then vestibular motion cues are largely responsible for the acquisition of tracking skills. Lastly, two studies (Go et al., 2000, 2003) used tasks that could be defined as disturbance management; specifically these were engine failures at take-off. These studies did not show significant transfer of training

differences with the inclusion of vestibular cues. The lack of increased transfer might be attributed to the dynamics of the disturbance task used. In both studies the disturbances were transient in nature as opposed to creating continuous perturbations within the control loop. It might be possible that these transient disturbances did not generate enough of an effect to elicit significant results. Within a ground vehicle, continuous disturbance are much more likely to occur when operating off-road due to the effects of terrain. It is possible that if continuous disturbances of the type more common in a ground vehicle were examined, transfer of training differences resulting from the inclusion of vestibular motion cues may become apparent.

Motion Sickness

Moving environments can often cause uncomfortable symptoms that are classified as motion sickness. Symptoms most often associated with motion sickness are headaches, nausea, vomiting, sweating, salivation, dizziness, and apathy, just to name a few. Motion sickness has also been classified more specifically depending upon the characteristics of the environment, such as air sickness, space sickness, and sea sickness.

Motion sickness can also occur in simulators, termed simulator sickness (Kolasinski, 1995). Typically, symptoms of simulator sickness are similar to other types of motion sickness. In some cases, individuals will suffer symptoms of motion sickness in a simulator but not in the real vehicle (Lampton, Kraemer, Kolasinski & Knerr, 1995). Concern over simulator sickness interfering with training has prompted the development of a measure of simulator sickness, termed the Simulator Sickness Questionnaire (Kennedy, Lane, Berbaum & Lilienthal, 1993). For a more comprehensive discussion of simulator sickness, see Johnson (2005).

Motion sickness in all of its forms is most likely caused due to stimulation or lack thereof to the vestibular system. The vestibular system is responsible for balance as well as spatial orientation of the body. The vestibular system detects motion with two structures within the inner ear. The semi-circular canals are small fluid filled tube like bone structures within the inner ear that can transmit rotational movements of the head. Working in parallel with the canals are the otoliths which is believed to register accelerations on the body being made in the x, y, and z-axes.

Motion sickness does not manifest itself the same way in all individuals. People who have had their vestibular system removed or damaged often do not experience motion sickness. Other individual differences have been found across populations. For example, it has been found that very young children and adults over the age of 60 are not as susceptible to motion sickness as others (Reason, 1968). Even the severity or causes of motion sickness can vary within the population. Individuals may not exhibit all of the symptoms or develop symptoms in every type of motion environment.

These individual differences may be due to experience levels with an environment. One theory of motion sickness is that it occurs due to sensory conflict. The theory suggests that if two sensory systems perceive the environment differently, the conflict may cause an individual to become ill. Reason (1970) expanded this hypothesis with the sensory rearrangement theory.

The sensory rearrangement theory suggests that symptoms of motion sickness occur because the human sensory system has evolved to expect sensory input from different perceptual systems to be congruent. Situations that produce motion sickness, such as riding in vehicles, are relatively recent in evolutionary terms. When people experience these situations, sensations from the visual, vestibular, and the proprioceptive system are at odds with each other, the sensory system does not have the means to resolve these differences, and symptoms of motion sickness occur.

These sensory conflicts have been categorized into two types: inter-modality and intra-modality (Reason & Brand, 1975). Inter-modality conflicts are characterized as ones in which two different sensory systems provide conflicting information, such as conflicts between the visual system and the vestibular system. Conversely, intra-modality is defined as conflicts that occur within the same system. For example, conflicts that occur within different structures of the vestibular system, such as between the semicircular canals and otoliths, would be intra-modality conflicts.

Inter- and intra-modality conflicts are further categorized into three sub-categories each. Tables 1 and 2 present the different categories of conflicts as defined by Reason and Brand (1975). Table 1 shows inter-modality conflicts, while Table 2 displays intra-modality incompatibilities.

Table 1
Inter-Modality Conflicts.

Conflict Type:	**Visual-Vestibular Relationship:**	**Examples:**
Type I	Contradictory sensations from both systems	• Use of binoculars in a moving vehicle • Movements of the head while vision is distorted.
Type IIa	Visual system sensations only	• Use of a motionless simulator
Type IIb	Vestibular system sensations only	• Reading inside a moving vehicle • Sitting inside a moving vehicle with no visual representation of its movements.

A further theory of motion sickness (Triesman, 1977) postulates that the conflict between the sensory systems leads the mind to think that the body has been poisoned. Since the human sensory system has not evolved to deal with motion-induced sensory conflicts, the body assumes the aberrant sensations are caused by an ingesting of toxins. Consequently, the body responds with the most appropriate reaction to poisoning, nausea and vomiting which are also the dominant symptoms of motion sickness.

Whatever the cause of motion sickness, there is no benefit to the physiological responses. In fact, the symptoms of motion sickness can interfere with task performance. Therefore, vehicle operators and passengers must develop strategies to counter the negative effects of motion sickness.

An operator in a mobile command and control vehicle (C2V) would probably be most susceptible to suffering from Visual-Vestibular Type IIb conflict. Fifty-five percent of Soldiers in mobile C2Vs have reported moderate to severe symptoms of motion sickness (Cowings, Toscano, DeRoshia, & Tauson, 1999). The symptoms most often reported included drowsiness, headaches, warmth, and nausea. Since slightly over half of C2V riders experience symptoms of motion sickness, the effects of such symptoms should be considered in the design of the vehicle and training of the Soldiers. Unfortunately, research suggests that seat layout does not significantly reduce the feelings of motion sickness (Cowings et al., 1999). However, adaptation to motion sickness symptoms through repeated exposure may reduce their ill effects to some degree.

Table 2
Intra-Modality Conflicts.

Conflict Type:	**Semicircular Canal-Otoliths Relationship:**	**Examples:**
Type I	Contradictory sensations from both systems	• Making head movements while rotating • Making head movements in a fluctuating environment, such as one with a linear oscillation
Type IIa	Semicircular canal sensations only	• Pouring water which is above or below body temperature into the ear, also called Caloric stimulation.
Type IIb	Otoliths sensations only	• Low frequency (below 0.5 Hz) translational oscillations

Training effects. Since motion sickness has deleterious effects on both performance and the individual's well being, considerable research has examined the possibility of adapting to motion stressors. Adaptation to sea sickness has been documented for centuries. Mariners and sailors refer to motion-sickness adaptation as "recovering your sea legs." Similarly, adaptation has been observed in astronauts who initially suffer from space sickness. As astronauts adapt to the microgravity environment, symptoms of sickness slowly decrease with time. Such evidence suggests that adaptation to motion sickness is possible. It would be beneficial to understand how adaptation occurs and also how it can be facilitated.

Reason & Brand (1975) found that adaptation to motion sickness can occur with exposure to motion stressors. Studies using an optokinetic tube found that over multiple exposure sessions

adaptation does take place (Hu & Hui 1997; Hu & Stern, 1999). An optokinetic tube is a large cylinder that surrounds an individual seated in the center of the tube. Large vertical black and white lines on the inside of the tube appear to rotate around the individual. This motion has been found to induce motion sickness in the majority of the population.

For one experiment, Hu and Hui (1997) had two groups of participants sit in an optokinetic tube for four 16 minute sessions. The first group was a nausea termination group who were allowed to leave the tube when slight feelings of nausea were felt. The second, non-termination group had to sit in the tube for the full 16 minutes, no matter what motion sickness symptoms were felt. Over the four sessions, symptoms of motion sickness decreased for both of the groups with a significant decrease in symptoms from the first to last sessions. Interestingly, the two groups adapted at close to the same rates even though the termination group had less exposure. This suggests that it may not be necessary for adaptation training to keep an individual in the motion environment after the initial symptoms of motion sickness are felt. Allowing a person to leave the motion environment prior to experiencing severe symptoms may make the experience less dreadful while still allowing them to adapt to the motion.

Although it is possible to adapt to motion sickness, it is likely the adaptation will decay over time. Historical anecdotes of sailors state that after several months ashore, some symptoms of sea sickness return when they go to sea again, although adaptation may occur more quickly.

Hu & Stern (1999) performed an experiment to determine how long the effects of adaptation lasted without motion stimulation. Participants were initially adapted to an optokinetic tube, and then re-introduced to the tube after a month of no exposure. The participants had symptoms that were very comparable to those of when they last had exposure, that is, they remained adapted to the environment. However, individuals that were reintroduced after a year had symptoms that were only slightly less than their initial exposures to the environment. This suggests that adaptation may be retained for a period of at least a month, but will probably decay after a year.

At times it may not be feasible to conduct adaptation training in a real world environment because of concerns over cost, safety, or availability of resources. For example, it would not be feasible to launch astronauts into orbit solely for adaptation training. Therefore, it is important to know if adaptation is transferable across different motion sickness inducing environments.

Research suggests it is possible to generalize adaptation across multiple environments. Adaptation and retention have similar rates for individuals across various motion environments (Graybiel & Lackner, 1983) even though the initial symptoms caused by these environments may vary greatly. Also, individuals adapt and retain the adaptation at similar rates regardless of the motion stimulation. Further, adaptation using physical stimulation (such as motion-based simulation or rotating chairs) tends to produce higher levels of tolerance to motion-sickness effects than video simulation that induces feelings of motion but no actual physical movement. Dobie & May (1990) suggest that to create a generalized tolerance to motion it would be best to have a high level of vestibular system stimulation during the adaptive training.

One caution, however, is that transferability of adaptation to motion sickness is not fully understood. Astronauts that have adapted to the space environment still sometimes develop sea sickness on their return to earth. The research above presents general guidelines for adaptation to motion sickness, but there may be variables as yet unknown which affect adaptation, or there may be significant differences between individuals as to how they adapt to motion sickness. Given this consideration, the best guideline for adaptation training might be to train using motion that stimulates the vestibular system as closely to the applied work environment as possible.

In summary, studies (Hu & Hui, 1997; Hu & Stern, 1999) have found that adaptation to motion sickness is possible and that training can reduce the symptoms of motion sickness through adaptation. Even though an individual may adapt to an environment, they may not be able to retain the adaptation after a long absence of the motion sickness inducing stimuli (Hu & Stern, 1999), and their adaptation will slowly decay from the last instance of exposure to sickness inducing motion cues. Transfer of adaptation from one environment to another can occur; however the environments should stimulate the vestibular systems in similar ways to gain the maximum benefits (Graybiel & Lackner, 1983).

Conclusions

Motion Cueing

Theoretical and basic research. Newer theories on motion cueing in a simulation training environment (Advani & Hosman, 2001; Hosman et al., 2002; Hosman & Stassen, 1999; Hosman & van der Vaart, 1990) assert that there are two general task characteristics that determine the necessity of vestibular motion cues during simulator training. The first characteristic is to which of Rasmussen's (1983) SRK taxonomy levels the task belongs. Specifically, Advani and Hosman (2001) argued that it is the acquisition of skill-based behaviors that require training with accurate system dynamics. This is because skill-based behaviors are driven by a dynamic world model of the control characteristics of the system and how that system interacts with its environment. Therefore, skill-based behaviors and the integration with the other levels of behavior should be trained with correct vehicle control characteristics. This can be accomplished either in the actual vehicle or in a simulator.

The second characteristic is whether the skill-based task is defined as tracking or disturbance management. Specifically, a series of experiments (Advani & Hosman, 2001; Hosman et al., 2002; Hosman & van der Vaart, 1981, 1990) have shown that for both ground vehicles and aircraft, vestibular motion cues become central in effective control when dealing with a disturbance. This is distinctly different from manual tracking tasks where visual motion cues alone were shown to be sufficient.

One of the questions that needed to be answered was whether research conducted on aviation simulation training could be generalized to ground vehicle simulation. The experimental evidence and perceptual models used in motion cueing research (Advani & Hosman, 2001; Hosman et al., 2002; Hosman & Stassen, 1999; Hosman & van der Vaart, 1981, 1990) have demonstrated that the relative contributions of visual and vestibular motion cues show a high degree of similarity between the control of aircraft and ground vehicles. Therefore,

it is assumed that applied research on the effects of motion cues on transfer of skills in aviation simulation can be used in the development of recommendations for the use of vestibular motion cues in ground vehicle simulation training.

Transfer evidence. Through a review of the research on the transfer of training in aviation simulators, certain relevant issues had to be addressed. First, Advani and Hosman (2001) and Hosman (1999) asserted that in order to train skill-based behaviors, accurate system control dynamics must be present. This would mean that simulator training should lead to increased transfer over alternate training methods in which these dynamics are not present. Studies comparing the effectiveness of simulator training to other methods (Gray & Fuller, 1977; Martin & Waag, 1978a, 1978b) have demonstrated the superiority of simulators over classroom instruction in the acquisition of manual control skills, thus showing evidence for this claim.

The second pertinent issue was the examination of experimental data demonstrating the relative contributions of visual and vestibular motion cues in training manual tracking skills. Advani and Hosman (2001) and Hosman and Stassen (1999) claimed that visual rather then vestibular motion cues are largely responsible for the acquisition and performance of tracking skills. Therefore, the addition of vestibular motion cues in a simulator should not increase transfer of training. These claims were confirmed by research (Jacobs, 1976; Koonce, 1974; Martin & Waag, 1978a, 1978b), in which it was demonstrated that the addition of vestibular motion cues in simulator training did not lead to an increase in the transfer of manual tracking skills over visual motion cues alone.

Lastly, an important issue was the relative effects of visual and vestibular motion cues on the training of disturbance management tasks. Advani and Hosman (2001) and Hosman (1999) claimed that while vestibular motion cues are not relevant for training manual tracking tasks, that they are a necessary component for training disturbance management skills. Therefore, an increase in transfer of training would be expected if the training of manual control skills under disturbance management included vestibular motion cues. Two studies that were examined (Go et al., 2000, 2003) included the training of disturbance management tasks. They did not show significant transfer differences with the inclusion of vestibular cues. The disturbances in these studies were transient in nature as opposed to more continuous types of perturbations resulting from factors such as rough terrain that would commonly affect an off-road ground vehicle. It might be possible that these transient disturbances did not generate enough of an effect to elicit significant results and that continuous disturbances of the type more common in a ground vehicle may elicit transfer of training effects.

Motion cueing recommendations. When looking at both the theoretical work on motion cueing and the applied transfer of training research, some recommendations can be made regarding the inclusion of motion in ground vehicle simulators.

1. For training basic driving and vehicle handling skills, motion is not required. These types of tasks are comprised almost entirely of tracking behaviors and both the theoretical work and empirical evidence from over 30 years of transfer studies have continually demonstrated that the addition of simulator motion does not aid in the transfer of tracking skills from the simulator to the actual vehicle.

2. For training more advanced driving skills, particularly vehicle handling in rough or difficult terrain such as sand, snow or rocky ground; or in dealing with very windy conditions, motion is required. These types of driving environments involve disturbances within the vehicle control loop and the theoretical and basic research on motion cueing has demonstrated the need for simulator motion with these types of disturbance tasks. In addition, if vehicle passengers are required to perform tasks while negotiating rough terrain, such as operating a computer workstation, a motion simulator should enable them to develop disturbance management strategies for performing the task. Even though the transfer research has yet to demonstrate an effect of motion with disturbance tasks, it is felt that this line of research has not focused on disturbance management to a sufficient degree to refute the findings of the theoretical and basic research in this area. Therefore, this recommendation is made in an effort to be conservative with regard to the available evidence.

With respect to the training of advanced terrain negotiation where motion is needed, this can be accomplished in two ways. First, is to use an actual ground vehicle for this type of training. This would obviously give perfect system dynamics in not only the visual and vestibular motion cues but also the interaction of the vehicle with the terrain. However, the availability of not only the vehicles but of a training ground that includes the various types of terrain is of particular concern. The second way to accomplish this training is to use a simulator with a motion base. Here attention must be paid to the motion base design to assure that the vestibular motion cues presented by the simulator are sufficient.

Motion base design. Advani and Hosman (2001) and Hosman et al. (2002) described a process for the optimization of simulator motion base designs. This was done in order to maximize the effectiveness of the vestibular motion cues presented by the motion system. While going into explicit detail about this process is beyond the scope of this report, it is important to mention since it has obvious implications for the design and use of Future Force ground vehicle simulators. Within this process, the design of the motion base is guided by the amount of motion cueing needed in each axis for the critical maneuvers that would be performed during training. Of note is the use of what is called the "coherence zone" for the perception of self-motion (Steen, 1998). This coherence zone describes the range of inertial angular rates that can be produced by the motion-base that are deemed to be the same as a presented visual angular rate. In other words, for a given amount of visually presented motion, there is a range of the amount of physical motion that will be perceived to be in agreement with it. This means that the amount of physical motion can be significantly less than what is presented visually with no reduction in the overall perception of self-motion (Groen, Bles, & Hosman, 2000).

Motion Sickness

Through a review of the work conducted on motion sickness, three relevant issues are important to training: adaptation, retention, and transfer. Adaptation to an environment with conflicting sensory cues can take place over repeated exposures (Hu & Hui, 1997; Hu & Stern, 1999; Reason & Brand, 1975). Although training facilitates adaptation within motion environments, adaptation decays over time. The adaptation to discomfort causing stimulation

will diminish from the last time an individual was exposed to motion cues (Hu & Stern, 1999) and motion sickness symptoms will return. Therefore, if an individual is trained in an environment, the adaptation that occurs will not last unless he or she periodically re-experiences that environment. The most relevant issue for the development of training simulators is the amount of adaptation that transfers to the real environments. Dobie and May (1990) and Graybiel and Lackner (1983) both showed evidence for the transfer of adaptation from a training environment to others, however for the best transfer the adapting stimuli should be as close to the real world environment as possible. If the real world motion stimulates the vestibular system in a significantly different way than the training stimuli, transfer of adaptation will be hindered.

Motion sickness recommendations. Recommendations on using motion stimulation during training have been developed based upon research conducted within the field of motion sickness.

1. The symptoms of motion sickness can be significantly reduced through multiple exposures to the sickness-inducing environment. A significant portion of the population will adapt to motion-sickness producing environments (Hu & Hui, 1997; Hu & Stern, 1999; Reason & Brand, 1975), but the amount of exposure needed for adaptation varies due to individual differences.

2. Allowing individuals to become seriously ill during adaptation training is not recommended as it will provide no extra benefit for acclimatization to motion sickness (Hu & Hui, 1997). Mild symptoms of motion sickness seem to facilitate adaptation as effectively as serious symptoms.

3. Continuation or refresher training should be provided periodically to retain adaptation to the motion environment, since adaptation decays over time (Hu & Stern, 1999). Adaptation to a motion-sickness inducing environment begins to degrade from the last instance of vestibular stimulation in the environment.

4. If a motion-based simulator is used to promote adaptation to a motion environment, the motion cues provided by the simulator should mimic, as closely as feasible, the cues experienced in the real world environment to maximize transfer of training (Dobie & May, 1990; Graybiel & Lackner, 1983).

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